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ENGINEERING FOR SUSTAINABLE DEVELOPMENT

"If you have built castles in the air, your work need not be lost; that is where they should be. Now put foundations under them."
Henry David Thoreau

INTRODUCTION

The year is 2035. A world burdened with over 10 billion inhabitants attempts to cope with unprecedented stresses on its natural systems and its social order.

The notion of global warming has become admitted reality, with devastating impacts on ocean currents, climate and weather. Dust bowl days have returned to the U.S. breadbasket, turning last century's grain surpluses into shortages. Rising sea levels have resulted in coastal inundation and saltwater intrusion into the world's estuaries and delta regions, causing unparalleled hardship in low-lying regions of India and Bangladesh. Once fertile agricultural areas have been irrevocably lost to an accelerated pace of desertification, while the destruction of both tropical and temperate forests has removed another 4,000,000 square kilometers of the earth's land surface from effective productivity during the last forty years. Food production of the earth's oceans, once seen as a cornucopia and salvation for humanity, has fallen dramatically as unsound management, steadily increasing pollution, and indifference have taken their toll.

Disparities between the more industrialized nations of the North and the developing nations of the South have become more acute, especially as many national economies have been bankrupted by the steady accumulation of debt and the exhaustion of their natural resources -- their only capital. Refugees from poverty, famine, natural and human-caused disaster, wars and political upheaval flow from stricken areas, far overtaxing the capacity of public and private relief efforts to alleviate the suffering. In short, a world gone awry, a world where the quality of life for the vast majority of its dwellers is at an all-time low.

Farfetched? Yet in a period of time as brief as that between our present and the end of World War II, this represents an outcome that may not only be plausible, but likely. Certainly likely, if the warning signs and voices of concern are apathetically ignored, and a "business as usual" attitude prevails.

Futurists, knowledgeable scientists, and, yes, even engineers, have attempted during the past few decades to articulate a new concept of global development -- one which, if followed, envisions a far brighter future than that painted above. It is a concept -- actually, a philosophy of survival -- that has come to be known as "sustainable development," variously defined and interpreted by its proponents. From the early 1970's, the United Nations has taken a leading role in these attempts to outline a better future, culminating in the 1985 publication of Our Common Future, the report of the U.N.-chartered World Commission on Environment and Development (WCED). This report has provided both a focused definition to and an impetus for the concept:

> [Sustainable development is] a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations. ... [It is] meeting the needs of the present without compromising the ability of future generations to meet their own needs.[1]

Numerous individuals and organizations have added their own slant on this definition since the publication of Our Common Future, bringing notions of ecological and environmental concerns to the forefront. As stated in 1990 by William Ruckelshaus, a WCED member and two-time former head of the U.S. EPA, "Sustainability is the nascent doctrine that economic growth and development must take place, and be maintained over time, within the limits set by ecology in the largest sense -- by the interrelations of human beings and their works, the biosphere and the physical and chemical laws that govern it."[2]

Sustainable development, however, encompasses far more than an integration of economic concerns with ecological or environmental constraints. It involves an understanding of societies and cultures, of the continued struggle between the affluent nations and those that aspire towards a better quality of life, of the need to balance the world's inequities and injustices. A sustainable world is a holistic "system" in the truest sense of the word, one in which these injustices are remedied, in

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1 Our Common Future, Report of the World Commission on Environment and Development, 1987

2 William Ruckelshaus, "Toward a Sustainable World", Scientific American, Sept., 1990

which a state of harmony exists among all humans, between humanity and nature, and between the present and future generations.

Within this context, civilian and military leaders alike have linked the need for sustainability to the very crucial issues of national and collective security and stability in a rapidly evolving multipolar world, where stability is seen as establishing the conditions which permit orderly change and which will allow democratic governments and market economies to flourish. These leaders have expressed the recognition that security in an unstable, environmentally-bankrupt world may be difficult, if not impossible to achieve. In other words, security, stability, economic and environmental concerns all become part of the equation that defines the future path of human existence on our planet -- a path that may be labeled "sustainability." In 1987, Soviet Premier Mikhail Gorbachev joined in this call:

> A world in which a whole continent can find itself on the brink of death from starvation and in which huge masses of people are suffering is not a safe world. Neither is a world safe in which a multitude of countries and people are stifling in a noose of debt.[3]

While the process of discussion and debate may continue, exploring the subtleties and implications of sustainable development, it is not the purpose of this paper to raise yet another voice in this dialog. For all their varying perspectives, proponents of sustainable development seem to agree that the basic conclusions are clear: there must be fundamental changes in our approach to future global development, and these changes must be initiated soon.

If these conclusions can be accepted, then it is time for a profession that has a vital stake in forging a better future to begin examining how this might be accomplished. This paper therefore seeks to define the role and responsibility of today's and future engineers in support of decision-makers, and to set forth a series of concrete steps -- foundations -- that can lead to a transition from words and concepts to actions and realities. It examines a future for engineering in which sustainability becomes not just an "add-on," but an integral part of every engineer's lexicon and decision-making process, as important as technology, environment, and economics. This integration process will not happen overnight, but it must begin.

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[3] Mikhail Gorbachev, "The Realities and Guarantees of a Secure World", Pravda, Sept. 17, 1987

THE ENGINEER'S ROLE IN SUSTAINABLE DEVELOPMENT

Who, or what, is an "engineer?" A succinct definition has been offered by Don V. Roberts, Vice President of CH2M Hill:

> It is the engineer who solves problems. He is faced with the need to deliver solutions within the constraints applied by time, money, and available knowledge. To fill his basic role as a problem solver the engineer must develop practical applications of available science or technology, combined with the experience gained in our profession, and the ability to adapt or modify existing approaches through innovation.[4]

This is a definition that expresses how most engineers, as well as those outside the profession, view in a very classic sense the practice of engineering: applying science and technology to real problems, with real constraints.

The future, however, will demand more of the engineer than the past -- a demand that will require perspectives to be changed and horizons broadened. Engineers can no longer afford to look at problems as part of a very limited system, but must consider each problem as a small piece of a much larger global system, with each proposed solution having potential impacts on the whole. Such a perspective comes from the adoption of a new set of values, of an engineering ethic that goes beyond the ethics espoused by technical and professional societies, and which places on the engineer a responsibility for finding sustainable engineering solutions. It is an ethic that expands the definition of an engineer beyond that of just "problem-solving'" to one of problem-solving with a specific goal: to enhance the quality of life for all humans, and of their environment. This embraces the very spirit and soul of sustainable development, and recognizes that every action, every consequence, must reflect an abiding interest in protecting, preserving, and restoring the quality of our environment and our global resources.

There is yet another dimension to engineering. Although the engineer must make frequent decisions as he or she explores solutions and alternatives, *large* decisions, related to whether or not a project is built or cancelled, a program started or delayed, a policy created or changed, are often in the hands of others. This does not imply that the engineer does not have an important role to play in many of these decisions -- advice is

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4 Don V. Roberts, "Sustainable Development -- A Challenge for the Engineering Profession", FIDIC Conference, Oslo, Norway, June 18,1990

usually solicited and considered -- but the role is primarily one of support, rather than decision-making responsibility.

This often results in situations where even sound solutions to significant problems may be changed or not implemented, due to factors over which the engineer has no control. As frustrating as this may be, especially to junior engineers, the fact is that senior leaders and managers, politicians, and financiers will continue to exercise much of the decision-making power, with most engineers serving in a supporting capacity. Therefore, the profession must recognize its limitations, without dwelling on the negative aspects of these, as well as its crucial responsibilities: to provide the very best advice and support.

What relationship does decision-support have to sustainable development? There has always been a time lag between problem-recognition and the willingness or ability of those in leadership positions to address it. In a political environment, reaction rather than proaction often appears to be the most expedient and safest path. As individuals and as a profession, engineers therefore have an educational responsibility to these decision-makers, to make them aware of the regional and global life-cycle consequences of each possible project, solution or alternative that is recommended. They must effectively communicate these consequences, consistent with a heightened awareness of their own values and ethics. They must approach all decisions, especially those over which they retain full control, within this value and ethical framework, recognizing that small decisions as well as large are important and can have an impact. Thus, a sustainable development ethic influences both their decision-making and decision-support functions as they seek solutions to future problems.

In musing over how the stewards of our earth can take the first steps towards a future of sustainable development, Ruckelshaus observed:

> To change interests, three things are required. First, a clear set of values consistent with the consciousness of sustainability must be articulated by leaders in both the public and private sector. Next, motivations need to be established that will support the values. Finally, institutions must be developed that will effectively apply the motivations.[5]

Engineers therefore can and should play a role in all of these steps. Articulation of values by leaders may come about through effective communication by engineers in their decision-making support role. New technologies, and a better application of existing ones, can help provide

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[5] William Ruckelshaus, op. cit.

some of the necessary motivation to adopt and support these values. Institutions, influenced by a profession that is committed to search for new answers to problems, will ultimately follow. In this overall role, engineers become *facilitators* of sustainable development, through the decisions that they make and those that they influence. In doing this, they rightly assume a leadership position. As Mark Wrighten, Provost of MIT, said when asked about today's engineering graduates, "Engineers are in a unique position to do something *significant*."[6]

BARRIERS TO SUSTAINABLE DEVELOPMENT

Given the growing body of evidence that our global process for continued growth and development has indeed gone awry, and that an approach that encompasses the tenets of sustainable development may be the only salvation, one might ask why engineers as a group have been relatively slow to "jump on the bandwagon" and embrace this philosophy. It is most likely not because the arguments for the necessity of sustainability have been ill-conceived or illogical, but that the hurdles between discussion and implementation are perhaps seen as too high or too many.

There can be no argument that these barriers are not formidable, or that their removal will not require an effort that must involve far more than the engineering profession. However, if engineers are to grasp the magnitude of their task as facilitators of sustainable development, both as decision-makers and decision-supporters, they must understand the issues related to some of these impediments. For discussion purposes, these obstacles may be grouped into three broad categories: macro-issues that transcend the practice of engineering, and over which the engineer may have somewhat limited control or influence (*external, non-technological*); those that are equally broad, yet basically technological in nature (*external, technological*); and those that are internal or self-imposed, and are a product of the experiential background and education of engineers (*internal*). Though the topics presented are by no means an exhaustive list, they at least portray most of the barriers that have received considerable attention during recent sustainable development dialog.

External, non-technological

Perhaps the most daunting challenge to sustainable development is the fact that the problems confronting us are truly global in nature, requiring

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6 Mark Wrighton, Provost of MIT, as quoted in "Now, Social Engineering", U.S. News and World Report, April 29, 1991

global solutions. While actions on the local or national level are no less important today than they have ever been -- local solutions may contribute to global answers -- they are insufficient by themselves to reverse the decades of neglect and indifference. As President George Bush remarked, "The plain fact is this: Pollution can't be contained by lines drawn on a map. The actions we take can have consequences felt the world over."[7]

But the problem goes far beyond that of controlling environmental pollution or degradation. We live in a world where growth, as measured by nearly every yardstick (population, industrial production, fuel and energy consumption, to name a few), has been rampant; where 25% of the earth's population consumes 80% of its output of goods and resources; where the gap between affluence and poverty widens; and where an uncertain future has been mortgaged to meet the needs and desires of the present. It is apparent to many that the earth's finite carrying-capacity, while perhaps not yet exceeded, is well within sight.

While it is not particularly difficult for most national leaders to grasp these facts, there is often a wide dichotomy between recognition and action. Political realities in every country influence national, and hence, global priorities. The affluent nations of the North, with sufficient capital to address environmental problems, now ask or cajole the struggling nations of the South into following their lead; yet these nations, burdened with debt and barely able to sustain the most basic needs of their populations, have a far different set of priorities, grounded in the present, that cannot respond to the needs of the future. Both the ability and willingness to act on such problems therefore become a function of affluence (however affluence may be perceived by a particular culture or nation), which in turn establishes national priorities and the political environment in which these priorities are met.

Changing these realities will require action of unprecedented nature and scale -- action which the world's leadership is only beginning to acknowledge:

> We believe that the attainment of sustainable development on the national, regional, and global levels requires fundamental changes in human values towards the environment, and in patterns of behavior and consumption, as well as the establishment of necessary democratic institutions and processes.[8]

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[7] Address by George Bush, Helena, Montana, Sept. 18, 1989

[8] Bergen Ministerial Declaration on Sustainable Development in the Economic Commission for Europe Region, May 16, 1990

As the bipolar world of the Cold War continues to evolve into a multipolar one, multilateral approaches to global problems have become a necessity. In this emerging world, nations are no longer islands, with their borders defining a self-sustaining system. Interdependence in security, economics, and environment have changed the very notion of national sovereignty, dictating a new era of multilateral accord and common management of common problems. While the search for sustainable development may be initially undertaken unilaterally, it cannot succeed without multilateral consensus.

Given a body of world history that completely contradicts the type and level of global cooperation that sustainable development demands, is there any hope for this effort to succeed? The answer is a guarded "yes," given certain intrinsic changes occurring in present society. Witness Europe:

> The most powerful force shaping Europe (and the world) is the rapid diffusion of power into the hands of individuals and factions who are freely and independently associating themselves with shared causes, not necessarily or even mostly identified with nationalism. ... That shift is the result of developments in the information technologies, particularly over the past 40 years, which have radically changed the speed, amount, and quality of information available to individuals.[9]

Clamor for the correction of past injustices, improvement in quality of life, and the end to the environmental rape of our planet is transcending national borders, creating new constituencies, with common goals and interests. Engineers have had, and will continue to have, a vital role to play in this process of disseminating the necessity for sustainable development -- through the further advancements in information technology, as well as in their voices raised in support of a new value system.

Complicating many of the global issues even further are the shortcomings and failures in the world's market-based economy to adequately assess or deal with the environmental dimensions of the marketplace. Market economics historically rewards production and consumption, gaging growth -- success -- by output of goods and services, and the harvesting or extraction of scarce, dwindling resources. Most economists would agree that the true costs of natural resource capital depletion, environmental pollution, cultural disruption, and ecological changes are not (and never

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9 Builder, Carl, and Banks, Steven, "The Etiology of European Change," RAND Report P-7693, Dec., 1990

have been) reflected by economic decisions that are made. As Jessica Tuchman Mathews notes:

> Subsidies, pricing policies, and economic discount rates encourage resource depletion in the name of economic growth, while delivering only the illusion of sustainable growth. ... Individuals and governments alike are beginning to feel the cost of substituting for (or doing without) the goods and services once freely provided for by healthy ecosystems.[10]

Whether these economic deficiencies are due to a lack of proper evaluation tools or models, an unawareness of the implications of the problem, or an unwillingness to make fundamental changes in our global capital accounting system is relatively unimportant. The fact remains that economics and environment have been disconnected, both in our decision-making process and in our institutions, and they must be merged if sustainability is to become a reality. President Bush commented in 1990:

> To exercise effective global stewardship, we must advance our knowledge of natural and human systems. We must create solutions that join economic growth with sound management of our environment. Meeting this challenge will require an integration of scientific, economic, and environmental concerns -- an integration which moves global stewardship and human sustainability to center stage.[11]

This integration imposes difficult and painful choices on a society that has become accustomed to dealing with traditional market economics. Consumer demand and decisions are based on competition -- however artificial or subsidized it may be. When this market-place competition fails to recognize long-term environmental costs, then current decisions become slanted in favor of short-term competitive considerations. The less-expensive refrigerator, with low energy efficiency, is chosen over the more expensive model. The product produced by the company that ignores its environmental responsibilities is selected instead of the more expensive product sold by the environmentally-conscious business. The barrel of oil that is burned is valued at its current market price, disregarding its potential impacts on the biosphere, or its resource capital depletion consequences.

In each of these examples, the consumption decisions avoid current costs by simply postponing them to the future -- letting a new generation build

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[10] Jessica Tuchman Mathews, "Redefining Security", Foreign Affairs: Current Issues, A Foreign Affairs Special Anthology, 1990

[11] From brochure prepared for the White House Conference on Science and Economics Research Related to Global Change, April, 1990

the additional power plants, clean the rivers, or solve the problems of global warming or resource scarcity. If substantive changes are to be made in market economics, with true life-cycle costs of capital resource depletion and environmental impacts reflected in the marketplace, then today's consumers must accept the responsibility to bear this burden, through either added prices or taxes, instead of passing these costs on to future generations. Again, this raises the issue of willingness of leadership, within a political arena, to tackle a problem with such ramifications.

Although engineers are generally cognizant of these nuances of economic theory, they are nevertheless educated and experienced only in applying market economics, as currently defined, in support of their decisions. Therefore, as project alternatives are screened and evaluated and as project-related decisions are made or recommended, the objective of maximizing net project benefits becomes of paramount importance. When the basis of this optimization exercise is flawed, then decisions are distorted, at least within the context of sustainable development.

Perhaps eventually society may develop more appropriate market economy tools, or exercise other options to account for true environmental costs. However, engineers cannot afford to use the current short-comings of the market-place as a crutch for avoiding the immediate need to begin selecting sustainable alternatives. Working within the confines of the current system, they must learn to apply a sustainability ethic now, even if only qualitatively, to their decisions. Therefore, the power plant designed to burn fossil fuel, with a better conventional benefit-cost ratio than an alternative that relies on renewable resources, may not be the one recommended to the decision-makers.

External, technological

After nearly a century of global growth and economic expansion, in which the earth's population has tripled and industrial output increased by a hundredfold, our society is only now coming to grips with the consequences of this development. Although a number of visionaries had raised probing questions about these consequences for decades, their voices were largely ignored (especially by world leaders) because of what was perceived as a lack of hard data -- scientific "proof" -- that profound changes to our ecosystem may take place, or were already occurring.

To provide this proof, the scientific community was presented with a problem that had two distinct, yet notably related, dimensions: predicting both the spatial and temporal (long-term) impacts of growth and technological decisions, with neither the predictive tools nor the global data to support them. In this vacuum, countless decisions were made, and projects designed and built, where even the best intentioned and qualified engineers could predict with any accuracy only the site-specific, short-term consequences of their actions. The crystal ball that would somehow look well into the future, or into the lands, oceans, and atmosphere far removed from a project location, was cloudy at best or, more likely, completely unavailable. Consequences of decisions were tabulated in terms of their potentially small marginal impacts on the global system, with no scrutinizing of the likely significant aggregate effects of <u>many</u> decisions, many projects.

In earlier societies, these prediction failures would have had no lasting impact. But in today's world, humanity has developed to the point where by the sheer size of the population, and the ramifications of its technology, it has the capacity to permanently alter its natural environment -- whether unintentionally or willingly. This has created the situation where forests of Europe and North America are dying due to air pollution and acid rain; where ozone depletion in the upper atmosphere threatens lifeforms of all types; and where changes in the very climate of the earth may affect the lives of coming generations. In the minds of many, the past failures of the scientific community to effectively predict or warn of these consequences has been equated to a failure of science and technology as an avenue to a better world. This has created an atmosphere of mistrust and suspicion, to the point where engineers will be faced with the need not only to develop assessment and prediction technology, but to sell this technology to a wary world.

The ultimate technological barriers to sustainable development, however, are far greater than those associated with assessment or prediction of the environmental consequences of our actions. They represent the <u>revolutionary</u> leaps that will be required if the technologists are to help open doors to a future where all individuals can truly share in the bounties of our earth. This denotes a concept of "sustainable abundance": not a profligate affluence, but an abundance where all needs are met; where each society and nation can achieve more and more with less and less; where humanity can aspire to a destiny not just of survival, but of flourishing in perpetuity on our planet.

It is difficult to conceive of the technological breakthroughs that may occur, or will be required, if this type of future is to be realized, but yet the technology of today would be equally astounding if viewed through the eyes of last century's generations. Whatever the past mistakes and failures of scientists or engineers, their technological advances have unquestionably improved the quality of life for vast numbers of people. As we muse about a future where sustainable abundance replaces unsustainable scarcity, the challenges to our research community, our educational systems, and all the supporting infrastructure are seemingly overwhelming. Yet, if we are to have a vision of such a future, technology holds the key to its achievement.

Internal

To understand more fully why the engineering profession has been slow to adapt to the needs of sustainable development, it is necessary to explore, at the risk of stereotyping, the personality, education, and experience of the "typical" engineer. This is presented not as an exercise in criticism, but in an attempt to explain why many engineers perhaps view the world differently than many of those who have led the call for an adoption of a sustainable development ethic.

For decades, psychologists and behavioral scientists have studied the make-up of human personality -- that vague collective word that describes the uniqueness of individuals, how they think and process information, express themselves to others, and interact with the people and world around them. One body of research suggests that there are at least four distinctly different categories of learning and information processing styles, and that the general population is almost evenly divided among these. Testing by Williamson and others[12] of freshmen entering university engineering programs indicates that, by and large, this pool of potential degree candidates exhibits the same division of personality traits as the general population.

However, by the time that graduating seniors are tested, this categorization has changed dramatically (primarily through attrition), with the overwhelming majority of those who have completed their education grouped into only two of the defined styles. Although these styles are themselves somewhat different (one represents learning by didactics and analysis, the other by hands-on experience), they have a number of common characteristics: they represent individuals who are pragmatic, task-oriented problem solvers; who analyze and organize their information and tasks in a very linear, step-by-step manner; and who work and learn best by interacting with facts and information, rather than people.

Who has been lost in this attrition from four styles to two? The "feelers" and "visionary intuitors" who learn and thrive by interpersonal

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[12] To be supplied later

relationships and human interaction, enjoying the sense of being a member of a team; who focus on the forests instead of the trees; and who analyze information in a more circular, iterative manner. This is precisely the type of person who can more easily accept and carry out the concepts of sustainable development, adjusting their vision of problem-solving to include a more holistic perspective. In the words of Gerald Wilson, Dean of Engineering at MIT:

> Our failure is in developing engineers who are too narrow in their understanding. Engineers who..."worship facts, rules, equations, and predictability": who rate high on individual achievement -- but who are not prepared or inclined to be members of multidisciplinary teams.[13]

In addition to common personality traits, engineers also share a common, highly-structured educational experience, one that is heavily influenced, if not imposed, by the accrediting organization (ABET) that reviews engineering programs at universities throughout the U.S. Whatever the specific discipline, all engineers are expected to have, among other things, a certain number of courses in mathematics, the basic sciences, and engineering fundamentals, along with a limited, broad-brush background in the humanities and social sciences. While this type of program is designed to graduate a well-rounded individual, with specialized education in his or her specific discipline, the "rounding-out" stops short of those subjects and areas crucial to an understanding of sustainable development

Very few engineers ever take a course in biology, ecology, or any other environmental science, and these topics are not included within the Engineer in Training (EIT) exam taken by college seniors as a prelude to professional engineering registration. Even civil engineers, representing a discipline that has traditionally had an active involvement in environmental issues, may graduate without any coursework in the sub-discipline of environmental engineering. The sad fact is that while society may expect all engineers to have developed, through their educational process, a full awareness of and the abilities to deal with the environmental consequences of their decisions, most are woefully lacking in any form of training. In this respect, they may evidence a level of environmental naivete no different from many of their non-engineer peers.

Therefore, since basic engineering education does not accomplish this task, society must assume that career experience will somehow fill in the gaps.

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[13] Gerald Wilson, "Engineering Education: A National Agenda", Executive Speeches, June, 1989

Unfortunately, this is not happening. In fact, many civil engineers in private practice, or working for private companies, continue to see the environmental dimensions of their projects or decisions as "add-on" tasks in a linear sequence -- with these concerns to be handled by someone else, as tasks completely divorced from the main objectives. Environmental policies, regulations, and requirements for environmental impact statements are often discussed in disparaging terms, and viewed as "necessary evils" that accomplish little else than to delay project schedules and cause budget overruns.

All of the negative aspects of these factors -- personality, education, and experience -- combine to define an array of problems internal to the engineering profession, that must be successfully overcome if engineers are to become facilitators of sustainable development.

A PROCESS FOR CHANGE: TOWARDS "NEW ENGINEERING"

Scholarly discussion of sustainable development and the mechanisms for overcoming the broad barriers to its achievement continues to take place throughout the world. Yet, as one observer noted, "If we'd been paid 50 cents for every word that's been written on sustainable development to date, we'd be wealthy. If we'd been paid 50 cents for every action taken, we'd be paupers."[14]

What are the costs of this inaction? On every scale -- from local to global -- they can be seen with stark clarity, as productive soils are lost to desertification and erosion, forests are converted to barren landscapes, nurturing wetlands disappear at alarming rates, and global biological diversity is threatened by an extinction of nearly 150 species of plants and animals each day. Action is not only needed, but it is needed <u>now</u>.

For the engineering profession, this transition from discussion to action requires a movement away from the emphasis on philosophical discourse at the macro-level, towards a set of realistic, concrete steps that can be implemented at the micro-level -- the day-to-day practice of individual engineers. These steps must be utilitarian enough to have an immediate impact on the problem, yet sufficiently abstract to allow for a flexible interpretation of the approach. While this is no simple task, similar efforts

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14 David T. Buzzelli, President and CEO, Dow Chemical Canada; as reported in <u>Sustainable Development: A New Path for Progress</u>, The Global Tomorrow Coalition, 1990

have begun in other arenas, leading to, for example, the "Valdez Principles" proposed by the Coalition for Environmentally Responsible Economies project of the Social Investment Forum. These broad principles provide industries with a voluntary means of embarking on a long-term process of initiating and institutionalizing a commitment to environmentally-sound business decisions.

Therefore, presented here is an initial effort at proposing a similar set of precepts for the engineering profession -- a list of eleven "sustainable engineering" principles that has the potential for bringing about some of the changes that are so desperately needed. Each of these eleven items is directed at the individual engineer, although most have significant implications on those organizations for whom the engineers perform their work. Throughout the list, issues of morality, values, and ethics permeate a call for new approaches to the practice of a profession that affords society with some of its greatest opportunities for achieving a better world. Although thoughtful individuals may debate, as they should, the specific principles in this list, the intention is to provide a challenge to the profession, and a first step in the process towards a "new engineering" and a new engineering ethic.

1. Become environmentally educated

There is an unfortunate perception among many engineers that they are already practicing sustainable development; that as long as they have at least complied with environmental requirements, they have met their responsibility to society. Many see project tasks that relate to the environment purely as the domain of someone else -- the environmental engineer or scientist -- and that as long as these tasks are performed, sustainable development will naturally follow. These perceptions and attitudes display a profound misunderstanding of what sustainable development is all about. They exist primarily because of a lack of any meaningful general environmental education, a lack that has stunted the hopes for instilling a universal environmental ethic in the minds of <u>all</u> engineers.

Therefore, before engineers can assume a necessary leadership role in the movement towards sustainable development, these deficiencies in their environmental education must be remedied. Although the eventual accomplishment of this must take place through the promulgation of an environmental and sustainable development ethic at the lowest levels of our educational system, followed by the revamping of university-level engineering curricula, these actions will not solve the problems faced by the current generation of practicing engineers.

These individuals, already burdened by the demanding task of keeping abreast of the explosive changes in technology occurring in every discipline, must accept the additional challenge of becoming better informed on environment-related issues. Whatever their discipline, the promotion of sustainable development demands that they cultivate an understanding of the issues, the problems, the array of available sustainable engineering solutions, and, especially, the potential impacts of their daily decisions.

This process requires reading, studying, taking an occasional short-course, and, most importantly, beginning to apply an expanded awareness to professional practice. This form of "action learning" is nothing new for most engineers, since a program of continuing education is generally part of each career. What is different, however, is the suggestion that the need for continued specialized education in their own discipline's expanding technology, and the need for more generalized education across the broad environmental spectrum, are equally important, and are in fact a career responsibility.

It should not be inferred from this that the average engineer's role should become one of environmental "expert." If anything, the type of generalized education that is suggested will lead to an awareness of the complexity of environmental problems, and that the engineering profession, on its own, cannot solve them successfully. The environmental generalist will learn to recognize his or her limitations and the importance of bringing other specialized expertise into the problem-solving process. Therefore, environmental education should include not only technical skills, but also the management and group-dynamics skills necessary for the engineer to interact and work with other professionals, other disciplines.

Organizations that employ engineers have a corresponding responsibility to encourage and reward the environmental education of their employees. But their responsibility does not end with this. If real progress is to occur with the next generation of engineers, there must be a strong top-down lobbying effort to make fundamental changes in an educational system that has yielded a condition of environmental naivete. This effort must be applied to all levels of education, but certainly to the university engineering curricula that are now so barren of any environmental coursework requirements, or requirements for engineers to work as members of multidisciplinary teams. For sustainable development to become a reality, the engineer of the future must be one who, in the words of Gerald Wilson, "understands how technology can benefit a beleaguered planet, not add to its woes."[15]

2. Expand your concept of environment

As the word "environment" has come to be part of our almost daily language, its meaning has often taken on a rather one-dimensional scope. To many engineers and non-engineers alike, environment only relates to our natural surroundings -- the air, land, water, and organisms that define the ecosystems of our planet -- and so-called environmental issues are usually viewed within this same context. But the dictionary definition is more precise and certainly more encompassing: "the total of circumstances surrounding an organism [including] the complex of social and cultural conditions affecting the nature of an individual or community."[16]

If the engineering profession is to help carry out the process of sustainable development, then engineers must also recognize that their environmental knowledge and responsibility should include this much broader concept of the environment, where the impacts of engineering decisions on each element of society -- its institutions, its values and culture, its economic and political systems -- are as fully considered as those impacts on the earth's natural environment. Development that does not occur in harmony with a society or its culture is as unsustainable as that which pollutes the waters or misuses scarce resources.

The expansion of our concept of environment to what might be called the "complete environment" implies a corresponding change in the manner in which we define project "systems." For years, engineering system boundaries were drawn to exclude the natural environment, treating it as an external factor. Just as engineers have come to accept the necessity for bringing it within the system boundary, they must also carry social and cultural conditions inside the system. This results in a holistic system where society, culture, natural environment, and technology interact and jointly affect problem solutions and decisions.

3. Practice, not just preach, a multidisciplinary approach

An in-depth understanding of the "complete environment" represents an impossible mission for any single engineer or, for that manner, any group of engineers -- even those who have become well-educated environmental generalists. Therefore, an expanded concept of environment demands that

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[15] Gerald Wilson, op. cit.

[16] The American Heritage Dictionary of the English Language, New College Edition, 1976

a true multidisciplinary approach to problem-solving and project engineering be adopted. Roles of engineers, planners, social and natural scientists, and all the other associated disciplines must become thoroughly integrated throughout the life-cycle of any project. Within this integration, team analysis, synthesis, and decision-making therefore replace unilateral decisions by any one profession.

While it is relatively easy to preach multidisciplinary approaches, it is a far more difficult task to put them into practice. It involves a commitment by all team members to listen, share, cooperate, and <u>function</u> as a team. It demands communication skills to convey ideas, feelings, and visions among the team members, approaching each problem with the collective wisdom of the group. Most importantly, it requires that engineers recognize that synergistic problem-solving ultimately leads to creative solutions that are of a higher quality than those derived from isolated analysis by any single team member.

The implications of implementing this level of team approach from start to finish are substantial. As previously pointed out, most engineers have neither the educational preparation nor the inclination to function as members of multidisciplinary teams. Many organizations lack the requisite skills in the involved disciplines to constitute the type of team that is suggested. Organizational barriers exist, especially in large companies or agencies, with many of the disciplines artificially segregated or compartmentalized into separate departments and reporting authorities. Engineering teams, accustomed to calling in "outside" advice only when absolutely essential (too frequently, in a crisis atmosphere) must learn to accept continual input and shared power. But these changes must necessarily come about as the profession begins to develop a heightened sensitivity to the linkage between sustainable development and the full meaning of "environment."

4. Listen and react to the society that you serve

Sustainable development must be thought of as a dynamic process that mirrors the continually changing needs and expanding knowledge-base of the specific society, culture, and community in which engineers work. Without an awareness of and a reaction to these societal needs, the best intentions of engineers towards achieving sustainable development will be doomed to failure. Our profession has often been guilty of hearing, but not listening to, the voices of concerned citizens whose lives are intimately affected by the projects that are built. Engineers become so caught up in the wonders of their technology and the creation of "things" that they often forget the importance of <u>people</u>.

It is not that engineers are unaware of or inexperienced in the "public participation" process. In fact, many of them have been involved with projects performed under the requirements of the National Environmental Policy Act or the Water Resources Council's "Principles and Guidelines for Planning," both of which mandate public participation. Yet, for the participatory process to become a successful contributing factor to sustainable development, it must be accepted by engineers as essential, rather than incidental, to the practice of engineering. Equally important, it must begin at the very earliest stages of every project, replacing an approach that has been described in the following words:

> Sometimes there is tension between agencies and the public because the public's role in the decision-making process is not clearly defined. For example, it is not uncommon for agencies to promise "public input" and then simply announce and defend the agency position at a public hearing, affording citizens the opportunity to do little more than to get their objections on the record.[17]

say more

Listening and reacting to society means including the lowest levels -- the individual voices of the community -- as well as the politicians and leaders. It also means promoting a new climate where cooperation and coalitions replace confrontation. For too long, engineers and environmentalists have been at odds with each other, adopting an adversarial stance that has been detrimental to shared interests. It is time to forge partnerships and alliances that can help to overcome the built-up mistrust, as both groups attempt to respond to the society in which they work.

Within this overall process of linking the power of technology and science to the needs and desires of society, the role of the public service engineer deserves special mention. More so than any other engineer, this individual is directly responsible to the society that has empowered him or her to represent it. This role requires an especially keen ear that can truly listen to the cacophony of needs and desires expressed by the many diverse elements of this society, coupled with an acute sensitivity to concepts of sustainability. In many cases, the public service engineer may be vested with the added responsibility of assuming a leadership position in promoting and institutionalizing the tenets of sustainable development. Whatever their roles, their commitment to embracing and applying a sustainability ethic must exceed that of most other engineers. This is a

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[17] Hance, Chess, and Sandman, "Setting a Context for Explaining Risk", Risk Analysis, Vol. 9, No. 1, 1989

high calling, and will demand a great deal from these engineers during the coming years.

5. Celebrate diversity

From its ecosystems to its human cultures, we live in a world of incredible richness and diversity, where each segment contributes in some way to the fullness of human experience and gives meaning to our lives and the lives of future generations. Most natural and social scientists would agree that this display of diversity is the evolving product of fundamental natural creative processes that have existed since the earth's infancy.

For decades, if not centuries, as these processes have been altered or circumvented by human intervention, a steady erosion of this diversity has become symptomatic of unsustainable development. Yet the problem goes far beyond the accelerating extinction of plant and animal species. It is seen in the loss of cultures, art, music, languages -- even native people. It is exacerbated by the ways in which technology has been routinely applied without regard to the the social and cultural uniqueness of each society for which it has been intended. This has led in many cases to "cultural homogenization" in which the culture and values of the technologists have been imposed on the "beneficiaries" of their technology, frequently yielding unintended or unwanted changes to a recipient's lifestyle, culture, or values.

If analogies to natural systems can be used, this homogenization bears a cost: non-diverse systems are less stable, more easily susceptible to threats, and require greater external subsidies to survive. While these characteristics have always been observed in natural ecosystems, social scientists have begun speculating that human social and cultural homogenization may have similar implications.

As engineers gain a more complete understanding of sustainable development and environmental issues, and learn to listen and react to the expressions of society, it will become increasingly obvious that the world can no longer accept a stock set of technologic solutions to the problems that confront it. Engineers must in this respect become divergers, rather than convergers, as they expand their sets of solution alternatives to reflect human, as well as technology, differences. "Off the shelf" answers must be replaced by solutions that are uniquely tailored to each combination of problem and set of societal needs, constraints, and opportunities. This challenge will require engineers to both recognize and respect the uniqueness of each society that they serve, and to emulate nature's processes of diverse creativity in applying technology to the search for sustainable development.

6. Broaden your scope of responsibility
This principle lies at the heart of the engineer's role in sustainable development, and implicitly demands that the engineering profession embrace a new ethic -- one committed to the necessity for applying sustainable development considerations to every single decision. As H.J.M. de Vries, a Dutch economist stated, "Sustainability is not something to be *defined*, but to be *declared*. It is an ethical guiding principle."[18] Such an ethic redefines the limits of the engineer's responsibility. It expands the concept of accountability, and can profoundly alter the engineer-client relationship. Yet it is a prerequisite if sustainable development is to occur.

To adopt a sustainable development ethic requires that engineers extend their view of projects beyond traditional horizons and time-lines, examining every project and project-related decision in terms of not only its local consequences, but its sustainability implications in a national, regional, and global context. Similarly, these consequences must be judged within an expanded time-frame, as the finite perspective of "short-term" or "project life-cycle" gives way to the more infinite perspective of "long-term."

Most engineers will continue to practice at the very local level, where their projects are limited in scope and size. However, with an ethic that involves a responsibility that transcends the local framework, engineers must begin to see how their local decisions, their small projects, can make a contribution to global solutions. They must also develop an awareness of how relatively minor local impacts are nevertheless another contribution to global problems, another "nail in the coffin." While it is a wonderful intellectual exercise to postulate global solutions to global problems, the truth remains that sustainable development can and should begin with actions at the local level. In fact, since many global problems are the sum of many cumulative actions, local action may be the only viable approach:

> To make an impact on the major global environmental problems will require lifestyle changes and changes in the ways our entire society functions. The manner in which our current states and national governments operate ensures that they will be

[18] Quoted by Paul Rothkrug in "A Program for Action", Mending the Earth, ed. by Rothkrug and Olson, 1991

the last entities demanding this.... Local action and local legislation opens doors to what is politically possible in the larger arenas.[19]

The true challenge for engineers will be to communicate effectively to their employers, clients, and society the consequences and risks associated with each alternative that is proposed and evaluated, and to guide the decision-making process in the direction of sustainable development. This will be inherently difficult if the engineer's perspective is broader than that of the client or local community. At times it may be impossible, and decisions will be made contrary to what the engineer recommends as sustainable.

What is the engineer's response to what may be viewed as an ethical dilemma? Today, our profession is guided by codes of ethics adopted by professional societies and licensing boards -- codes that stipulate that when a client's desires or actions conflict with the ethics of practice, the engineer has the responsibility to sever the engineer-client relationship. For the individual or organization subscribing to these codes, this is a painful action that must occasionally be taken. In a similar fashion, if the profession is to become committed to a new ethic of sustainable development, then it must be prepared at times to step away from projects that clearly violate this ethic. While these actions by themselves may not reverse political decisions, nor bring about immediate changes in society's priorities, they will set a necessary standard -- one that says that the profession has a responsibility to the planet's future.

7. Become synthesizers, not just analyzers

The problem-solving skills that engineers traditionally learn are ones of analysis, and not synthesis: they are taught to break down each problem into its simplest pieces, study each piece, and use the results as input to the next component or phase. This linear procedure is almost the antithesis of synthesis, which involves the <u>combining</u> of separate elements to form an integrated and coherent whole.

If sustainable development is to be approached (as it must be) in a manner that imitates the complexities of natural processes, it must be considered by engineers as a multi-dimensional, circular process, instead of linear. Each element provides input to and receives feedback from every other element, as the entire system continually responds and resonates to the options and decisions that are exercised internally or imposed on it

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[19] Nancy Skinner, "Grassroots Political Action", <u>Mending the Earth</u>, ed. by Rothkrug and Olson. 1991

externally. Thus project factors that pertain to economics, culture, environment or technology are all intertwined and significantly influence each other and the entire system. What is called "engineering" becomes in this scheme a unifying discipline, as opposed to a single part of a puzzle -- as it has far too frequently been seen in the past:

> The problem isn't so much with any of the steps. It's that they are "individual steps." We have treated engineering as merely one cog in the wheel. And we are paying the price.[20]

As an example of the inherent differences between circular and linear thinking, Don Roberts[21] has suggested that a general model of resource use and consumption be examined. In a linear representation, resources are drawn upon, then modified to create end products, which are finally transported and consumed by society. With each step considered as a single element, decisions are independently made concerning issues of technology applications, economics, waste disposal and impacts, and energy consumption -- a classic example of sub-optimization. With a circular model, however, the entire sequence is examined as a complete system, altering the overall manner in which optimization objectives such as minimization of energy consumption or waste generation might be solved.

This same analogy can be applied by engineers as they initiate every project. The linear CPM and PERT diagrams that engineers typically use to lay out project task sequences must be conceptually modified to include continuous feedback loops among all the elements, indicating integration and synthesis instead of simple linear paths from start to finish. Concerns about economics, culture, environment, and technology become merged within this process, since they affect every single element and task. The project team is then able to ask better questions, look for better data, and seek better solutions. True optimization with a sustainability objective, rather than sub-optimization using economic objectives, is performed. As project teams of the future become multidisciplinary in nature, the engineer's role becomes one of a synthesizer, integrator, and organizer, not an analyzer working in isolation. The engineer becomes a leader of this synthesis process.

8. Emphasize sums, rather than pieces

Engineers function in a society that has established a multitude of regulations and requirements that affect their practice. As applied to

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20 Gerald Wilson, op. cit.

21 Don V. Roberts, op. cit.

projects, these regulations cover everything from job safety to environmental protection, and influence countless project-related decisions. Within the constraints that they impose, engineers have become accustomed to applying a "pass-fail" criterion to project decisions, with each regulation, each requirement becoming a hurdle that must be overcome or somehow dealt with before moving on to the next one. They have learned to think in terms of "pieces," rather than sums.

As any competent math student could describe, this thought process leads to a binary representation of the world, where everything becomes either a "zero" or a "one." When project consequences are viewed in this light, each impact is assigned a zero as long as it marginally satisfies whatever regulation or requirement it must meet, and therefore when these impacts are summed, a zero total is achieved -- an apparently successful project.

Sustainable development demands more than this. It requires that engineers begin to examine more carefully the aggregate consequences of the individual impacts or decisions, emphasizing a holistic perspective that encompasses the net contribution to sustainable development. This approach moves beyond "environmental protection," which is not synonymous with sustainable development, into a broader arena where projects as a whole are tested against sustainability criteria.

It may be difficult for engineers to communicate the results of this test to decision-makers, clients, or the public. To indicate that a project which has succeeded in passing through each regulatory wicket should, in fact, not be pursued because its aggregate consequences violate sustainability criteria may be seen as heresy. On the other hand, specific projects that fail to pass certain individual requirements, or even fail a net sustainability criterion, may very well have a positive impact on sustainability when examined as part of broader and more comprehensive strategies. The engineer's task, therefore, is to effectively explain these apparent paradoxes, and to provide decision-makers with a set of constructs within which they can accept a holistic assessment of project value.

9. Select technology consistent with sustainable development

The engineer as a project team leader or member bears much of the responsibility for recommending the technologies that are applied to each project. The ultimate choices that are made have a crucial impact on whether the project represents sustainability, or becomes another example of a project yielding problems instead of solutions. As engineers weigh their options and make decisions, the recommended technologies should be influenced by two broad and related requirements: the need to anticipate the future life-cycle consequences of any proposed technology; and the need to balance the demands of this technology against the capabilities of the user.

The requirement for life-cycle considerations of consequences is wide-ranging, running along the time dimension from project planning through construction, operation, deactivation, and beyond; and spatially from local to regional to global. It involves, as previously described, the "complete environment" -- those equally important factors of ecosystems, society, and culture. Within this multi-dimensional matrix, each technology choice must be evaluated as to its impacts on sustainability, and compared to other alternatives.

The need to link technology with the capabilities of the user or recipient imposes another set of constraints on the engineer. Development that relies on technology exceeding the technical capabilities of the user, the operator, or the maintainer is not sustainable. Neither is development that exceeds the recipient's institutional capacities to manage or effectively use the intended outputs. These considerations invoke old concepts of "technology transfer" or "appropriate technology," except that they go beyond these into a realm of true "technology cooperation" between the user and provider, in which needs, desires, and capabilities are jointly weighed beneath the umbrella of sustainable development, and these assessments drive the technology decisions.

Within this overall context, engineers must now begin to exercise technology options that specifically focus on improving the approach to resource use (including energy) and waste generation. Terms such as substitution, conservation, recycling, waste minimization, and environmental restoration must become daily bywords in our practice, guiding our decisions. Wherever possible, renewable resources should be substituted for non-renewable, and processes, products, and technologies that yield detrimental impacts must be replaced by those that do not. Resources of all types must be conserved, through more efficient use, improved conservation technology, or promotion of lifestyle changes. Recycling, resource recovery, reuse, and waste minimization must become components of every project and technology decision, since society can no longer afford the unsustainable practice of "use and discard." Finally, since development will always be accompanied by some form of environmental impacts, engineers must not only seek to avoid and minimize these impacts, but to more than offset the unavoidable ones by environmental restoration, at the project site or elsewhere.

Our profession, including public agencies and private companies, must open new and better technology options for the future, through research dedicated to energy and resource-use efficiency, improved recycling and waste recovery processes, substitution of environmentally safe products and processes for harmful ones, and more cost-effective and timely environmental restoration technologies. All these represent areas in which engineering can have some of the greatest impacts on promoting sustainable development, and where the profession should excel.

A total commitment to technology choices that advance sustainable development will be a change in direction for many engineers and for many future projects -- a change that will eventually affect the lives and lifestyles of every society. But, as Rupert Sheldrake said, "Recognizing the life of nature demands a revolution in the way we live our lives."[22]

10. Promote "environmental economics"

There is no doubt that at least in the short-term the earth's population will continue to grow. Although scientists disagree over the ultimate population that could be sustained within the finite constraints of the earth's carrying-capacity, many believe it to be roughly twice the current level. Using this assumption, economists estimate that to meet the basic needs of an added population, while at the same time assuring global security and stability by alleviating the economic inequities between rich and poor, North and South, a five- to ten-fold economic expansion must take place.[23] These same economists are careful to point out, however, that this expansion must represent true "development," as opposed to "growth":

> Economic growth, which is an increase in quantity, cannot be sustainable indefinitely on a finite planet. Economic development, which is an improvement in the quality of life without necessarily causing an increase in quantity of resources consumed, may be sustainable.[24]

Much has been written about the failure of market economics to properly account for the environmental costs of our decisions, or to assess the true values of our environmental assets. Yet history has taught us that, for all its shortcomings and inequities, a market economy based on a free

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22 Rupert Sheldrake, The Rebirth of Nature: The Greening of Science and God, Bantum Books, 1991

23 Our Common Future, op. cit.

24 Robert Costanza and Lisa Wainger, "No Accounting for Nature", The Washington Post, Sept. 2, 1990

enterprise system affords the best opportunity to achieve the level of global economic development that must occur. So within the limitations of sometimes distorted market economics, how does the engineer grapple with the need to practice "environmental economics," to evaluate the economics of projects in a manner that fosters sustainable development instead of unsustainable growth?

While we recognize that economic activity must account for its own environmental costs, it is naive to state that engineers must somehow factor into their economic analyses those costs that even skilled economists have difficulty in quantifying. Until improvements occur in our economic accounting procedures, turning intangible (but very real) costs and benefits into hard, bottom-line numbers, the engineer's responsibility is to develop an awareness of the implications these costs and to communicate them, even if in a qualitative manner, to others.

Decision-makers, clients, and the public must be told about the sometimes hidden trade-offs inherent in each decision, and be provided with enough information to balance the risks and sustainability costs of environmental consequences with the apparent benefits of each project. Short-term costs to consumers associated with electing sustainable development options should be contrasted to the long-term costs to future generations if unsustainable choices are made. The engineer, assuming the role of facilitator of sustainable development, becomes a communicator of economic consequences and promoter of environmental economics.

The engineering profession can and should participate in the efforts by economists to bring about fundamental revisions in our market-based accounting procedures, and to improve economic models that reflect long-term, global impacts of economic policies and decisions. It can lend its support to suggestions such as energy or consumption taxes that discourage unsustainable consumption practices, new definitions of GNP that include environmental implications, the elimination of market subsidies that distort environmental costs, the shared funding of restoration efforts in global commons or in less affluent nations, or other similar proposals. Its role should be to effect policy changes at every governmental level, policy changes that will enable society to recognize the real costs and consequences of its economic decisions.

11. Spread the word

There will be frequent near-term conflicts between the recommendations or decisions of scientists and engineers applying a sustainable development ethic and the expressed desires and needs of the society they serve. At times, the solution best suited to sustainable development may not be the one chosen by the decision-makers or the public. These conflicts are unavoidable, yet disastrous in the long-term if the technical community is unable to gain acceptance of the need to select the path to sustainability. This imposes a final responsibility on the engineering profession and individual engineers -- to educate all elements of society, and promote within the political system the universal adoption of a sustainable development ethic.

It would be overly optimistic to assume that urging engineers to write and publish papers on sustainable development in prestigious technical journals will accomplish the necessary education of a global society. Nor will articles in popular magazines or newspapers, or television coverage, although these are all steps in the right direction.

Effective education must begin at the grassroots level, by engineers becoming personally involved in the affairs of their communities, interacting with other people, and, when possible, assuming participatory roles in community bodies with leadership and decision-making authority. It requires that engineers, contrary perhaps to their personalities, seek out positions on local Planning Boards, Wetlands Commissions, or similar bodies; that they volunteer to speak at town meetings or to address citizens' groups; and that they even run for public office.

The profession as a whole must reach out to an even broader audience, using the resources of professional societies to advertise and promote sustainable development. A strong global constituency has already been developed by environmentalists, and this should be tapped by the engineering profession as it looks for partnerships in disseminating the consequences of unsustainable development. Lobbying must occur on every political level as coalitions supporting sustainable development work to educate those with the authority to make decisions or enact legislation. Public engineering institutions can support these efforts by promoting pilot projects that exemplify the use of sustainability criteria -- setting examples for others to follow.

Thus, "spreading the word" becomes both a top-down and a bottom-up responsibility, to be shouldered by individual engineers, professional societies, and any alliances that they may be able to forge. It is an educational mandate for the profession that is ultimately more important than any it has ever faced before.

CONCLUDING COMMENTS

What has been presented here is a relatively simple set of eleven guiding principles for engineers who accept the challenge of their role as facilitators of sustainable development. How they apply these principles in their daily decisions, or how their employers or organizations interpret them, is a matter for future discussion and elaboration. The tasks of changing our perspective of the world, and fulfilling our responsibility to support sustainable development, are complex and difficult, yet essential if a sustainable future is to be within our grasp.

However these or similar principles may evolve, the process of implementation must begin soon. The concept of sustainable development must move beyond one of Thoreau's "castles in the air" to a structure fully supported by firm foundations -- foundations that can be built using the stones of these eleven principles. For engineering organizations, public or private, sustainable development must become part of the way in which they do business; for individual engineers, it must become a part of their lives. Each positive action, each small victory, moves the world closer to the sustainable future that it must have. One company, one agency, one engineer can make a difference.

Perhaps as a conclusion to these observations, it would be appropriate to look at just one example of where the paths of unsustainability have led us. It centers on the Columbia River system, a system that has been the life-blood of the Pacific Northwest and for the Native Americans of this region, as well as for the settlers who displaced them. To meet the growing demands for power, improved transportation, and water for agricultural production, federal, state and private interests joined forces this century to harness and use these waters. Engineering marvels were constructed: the Bonneville, Grand Coulee, and Hells Canyon Dams, to name a few. These efforts contributed to an expanding population and industrial-base, increased output of goods and services -- in short, the economic growth of the region.

But there were also costs. As dams proliferated throughout the basin, and logging, mining, and ranching destroyed natural spawning habitat, the anadromous fish population (primarily, the many species of Pacific salmon) was put at risk. As one researcher notes:

> The greatest impact came from the construction of Grand Coulee Dam on the Columbia River and Hells Canyon Dam on the Snake River. These dams were considered too high for fish ladders, so nearly 2000 miles of spawning streams were simply walled

off. The fish that would normally have returned to these streams were left to die at the feet of the dams.[25]

When the Lewis and Clark Expedition reached the Columbia River in the fall of 1805, the salmon were returning to spawn, and their journals recorded "the number of dead salmon on the shore and in the water is incredible to say." Today's estimates of these spawning runs place the number of returning fish at less than 2% of the number observed by Lewis and Clark, with most of the decline occurring within the last 50 years. As examples, during the summer run of the Salmon River Chinook in 1970, 20,000 fish returned, and only 500 in 1989. The Idaho-bound Sockeye salmon, numbering in the thousands a few decades ago, is now virtually extinct (only 4 Sockeye returned in 1989). In fact, more than 80% of the species of wild salmon in the Columbia River basin have become extinct since 1940.

It is a soul-searching exercise to ask ourselves the question whether, in 1991, if faced with trade-offs of economic growth against the fate of the wild salmon, we would make any different decisions than those of 50 years ago. Would we opt for more limited development in harmony with nature -- sustainable development -- or maintain an attitude exemplified by a quote from 1937, as the Grand Coulee Dam was being constructed:

> There is real fear that the dam will just about abolish the $10 million a year Columbia River salmon industry...Well, that'll be just too bad, but, after all, its only $10 million a year. What's that trifle in these days of billions.[26]

The discussion continues today over what steps, if any, can be taken to halt or reverse the salmon decline. Possible solutions are vehemently opposed as irrigators resist a loss of water rights, consumers react to a potential 17% increase in their electric rates, and federal agencies debate their authority to act. No one wants to accept the burdens that these solutions would impose: added costs, inconvenience, changes in consumption patterns. Meanwhile, the salmon runs dwindle, and new species are poised on the precipice of extinction.

What value do we place on the last wild salmon? Or, perhaps sometime in the future, the last blue whale, or the last barrel of oil? Do we measure these costs in dollars, or simply with a deep sense of loss -- of a further

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25 Roger Martin, "Economic and Legal Feasibility of Converting Irrigation Water to Anadromous Fish Production in the Columbia/Snake River System", unpublished report, 1991

26 Jim Marshall, Colliers Magazine, 1937

diminishment of the diversity that used to characterize our finite and fragile earth?

We suffer from the consequences of unwise decisions and trade-offs passed down to us from prior generations, decisions which were usually made in ignorance. Yet today, despite our expanded knowledge and awareness of the consequences, we often consciously elect to follow the same path. Our children, and their children, deserve better. It is up to us -- the engineers, the problem-solvers, the facilitators and stewards of sustainable development -- to see that they receive their heritage.